Electronics Engineer's Reference Book

Fifth Edition

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during temperature cycling and, in most of the types available at present, the temperature/capacitance curve is not entirely linear. There is also a wide spread of mean temperature coefficients between different specimens, even of the same batch.

The power factor of mica is approximately 0.000 3 at 1 Hz, but can be as low as 0.000 05 when specially selected and very dry. The permittivity is about 7. The current-carrying capacity of the silvered plate imposes a limit to radio frequency and pulse loading and the silvered-plate capacitor is therefore less suitable for heavy current work than the stacked-plate type, although the latter is less stable and cannot be made to such a close selection tolerance as the silvered-plate capacitor.

13.2.5 Ceramic-dielectric capacitors

Ceramic-dielectric capacitors (ceramic capacitors) are made in three main classes—low permittivity low-loss types, medium-permittivity temperature-compensating types and high-permittivity types.

The low-permittivity low-loss types are generally made of steatite or similar material. Steatite has a permittivity of approximately 8 and other materials may give permittivities between 6 and 15. Their performance at high frequencies, from about 50 Hz upwards, is excellent. The power factor is reasonably low (0.001), approaching that of mica. The temperature coefficient is between +80 and +120 ppm/°C and the capacitors are normally very cyclic in behaviour. The temperature coefficients vary less between different batches than for capacitors of any other dielectric except glass and vacuum. The capacitance stability in normal use is about 1% excluding temperature variations. They operate at comparatively high voltages, 500 V or so (depending on size), over a temperature range from about +150°C down to extremely low temperatures.

The second class, of medium permittivity (ε about 90), are used mainly as temperature-compensating capacitors in tuned circuits and have negative temperature coefficients of the order of −600 to −800 ppm/°C. They are all based on titania or its derivatives. The power factor is again low and may be less than 0.000 3 at radio frequencies. Other temperature coefficients can be obtained by using different mixtures.

The high-permittivity ceramic capacitors provide a very high capacitance in a compact unit. The capacitance and the power factor, however, change widely with temperature, the changes being neither linear nor very cyclic for either property. Capacitors using the $\varepsilon = 1200$ material, for instance, have a high capacitance peak (Curie point) at about 110°C, which is two or three times the value at room temperature, with another much smaller one at about −10°C. The power factor is a minimum around 20°C to 40°C and is in general around 2%. High permittivity materials with other permittivities have peaks at other temperatures. In general, the higher the permittivity, the more temperature-sensitive is the capacitor. In addition to changes with temperature, the capacitance is also reduced under d.c. voltage stress, especially at the peak points: at room temperature a reduction in capacitance of 10 to 20% will occur, but up to 50% can be expected at the Curie points. The d.c. working voltage is rather lower than the low-permittivity ceramic type. The capacitors are subject to hysteresis and accordingly are suitable for working with only very small a.c. voltages. They are used mainly as r.f. bypass capacitors, but can also be used for interstage coupling, provided the capacitance is large enough under all conditions of operation. The properties of high-permittivity capacitors, therefore, vary so much with temperature, voltage stress, etc., that no general electrical characteristics can be given.

13.2.6 Glass-dielectric capacitors

These capacitors are formed of very thin glass sheets (approximately 12 μm thick) which are extruded as foil. The sheets are interleaved with aluminium foil and fused together to form a solid block. Their most important characteristics are the high working voltages obtainable and their small size compared with encased mica capacitors.

Glass-dielectric capacitors (glass capacitors) have a positive temperature coefficient of about 150 ppm/°C, and their capacitance stability and Q are remarkably constant. The processes involved in the manufacture of glass can be accurately controlled, ensuring a product of constant quality, whereas mica, which is a natural product, may vary in quality. As the case of a glass capacitor is made of the same material as the dielectric, the Q maintains its value at low capacitances, while the low-inductance direct connections to the plates maintain the Q at high capacitances.

These capacitors are capable of continuous operation at high temperatures and can be operated up to 200°C. They are also used as high-voltage capacitors in transmitters.

13.2.7 Glaze- or vitreous-enamel-dielectric capacitors

Glaze- or vitreous-enamel-dielectric capacitors (glaze- or vitreous-enamel capacitors) are formed by spraying a vitreous lacquer on metal plates which are stacked and fired at a temperature high enough to *vitrify* the glaze. Capacitors made in this way have excellent r.f. characteristics, exceedingly low loss and can be operated at high temperatures, 150°C to 200°C. As they are *vitrified* into a monolithic block they are capable of withstanding high humidity conditions and can also operate over a wide temperature range. The total change of capacitance over a temperature range of −55°C to +200°C is of the order of 5%. The temperature coefficient is about +120 ppm/°C and the cyclic or retrace characteristics are excellent. As in the glass capacitor the encasing material is the same as the dielectric material and therefore all corona at high voltages is within the dielectric. They are extremely robust and the electrical characteristics cannot normally change unless the capacitor is physically broken.

13.2.8 Plastic-dielectric capacitors

In plastic-dielectric capacitors the dielectric consists of thin films of synthetic polymer material. The chief characteristic of plastic-film capacitors is their very high insulation resistance at room temperature. The main synthetic polymer films used as capacitor dielectrics are.

13.2.8.1 Polyethylene terephthalate

This is a tough polymer with high tensile strength, free from pinholes and with good insulating properties over a reasonably wide temperature range. This is known under a variety of trade names such as Melinex (ICI), Mylor (Du Pont), Hostaphon (Germany) and Terphane (France). It is commercially available in thin films of 3.5 μm in thickness.

13.2.8.2 Polycarbonate

This is a polyester of carbonic acid and bisphenols. It combines in good physical properties with a lower loss (or dissipation factor) than polyethylene terephthalate. It has a temperature characteristic nearer to zero and is available in film form down to 2 μm in thickness.

Table 13.3 Film material properties

	Polyethylene terephthalate	*Polycarbonate*	*Polystyrene*	*Polypropylene*
Permittivity (at 1 kHz)	3.2	2.8	2.5	2.25
Dissipation factor (at 1 kHz)	0.004	0.001	0.0002	0.0005
Dielectric strength (V/μm)	304	184	200	204
Insulance (Ω-F)	1×10^5	3×10^5	1×10^6	1×10^5

13.2.8.3 Polystyrene

This is a hydrocarbon material and has a lower permittivity than the previous two dielectrics. It has a better dissipation factor but its tensile strength for winding is much lower and 8 μm is the lowest film thickness available. It is not normally used in metallised capacitors unless heavily derated.

13.2.8.4 Polypropylene

This is a low-price material and has the lowest dissipation factor of the four films discussed. It is not commercially available in films less than 8 μm thick and it has a lower permittivity and its use is therefore limited.

A comparison of the electrical characteristics of the four film materials at 20°C is given in *Table 13.3*.

13.2.9 Electrolytic capacitors

The most notable characteristic of these capacitors is the large capacitance obtainable in a given volume, especially if the working voltage is low. Electrolytic capacitors are used for smoothing and bypassing low frequencies, but they can also be used for high-energy-pulse storage applications, such as photoflash and pulsed circuits. The electrical properties change widely under different conditions of use and some indication of these is given below.

13.2.8.5 Capacitance

There is a slight increase (about 10%) when the temperature is raised from 20°C to 70°C; a gradual decrease as the temperature is reduced to −30°C, and a very rapid decrease at lower temperatures. The capacitance also decreases slightly as the applied frequency is increased from 50 Hz giving a 10% reduction at 10 000 Hz.

13.2.8.6 Power factor

At 50 Hz and room temperature, the power factor is from 0.02 to 0.05. There is a slight increase at +70°C and a large increase at −30°C. A large increase also takes place as the frequency is increased and the power factor becomes about 0.5 at 10 000 Hz.

13.2.8.7 Leakage current

This is normally considered instead of insulation resistance, which is very low in this type of capacitor. The leakage current varies directly with temperature, having quite a low value at −30°C, but at +70°C it is about ten times the value at room temperature. In addition, the leakage current increases with the applied load, being very high when the load voltage is first applied, but it falls rapidly and after about a minute tends to reach a stable value.

13.2.8.8 Impedance

There is a gradual increase in impedance as the temperature is reduced, until at −30°C it is about twice the impedance at room temperature, while at still lower temperatures a much more rapid increase occurs. At temperatures above normal there are only slight variations. The impedance falls rapidly with increase of frequency and at 10 000 Hz is of the order of 2 Ω for a 16 μF capacitor.

The normal type of electrolytic capacitor is made using plain foils of aluminium, but considerably increased capacitance can be obtained by using etched foils or sprayed gauze foils to increase the surface area. Electrolytic capacitors need to be reformed periodically if they are stored for a considerable time. Reforming is carried out by applying the working voltage through a resistor of approximately 1000 Ω for one hour.

Tantalum-pellet electrolytic capacitors do not need reforming and have an expected shelf life of more than ten years. They have the advantage of even greater capacitance in a small volume and the leakage current is extremely small—of the order of a few microamperes—enabling them to be used in circuits such as multivibrators. They have lower voltage ratings, however, and some types are expensive, but they are capable of operating over a temperature range from −55°C to +125°C with negligible change in capacitance.

Tantalum-foil electrolytic capacitors are also extremely small in size and have a low leakage current. They can operate at higher voltages than the tantalum-pellet types, but cannot operate over as wide a temperature range. The power factor varies considerably with temperature, also with voltage rating.

13.2.8.9 Air-dielectric capacitors

Air-dielectric capacitors are used mainly as laboratory standards of capacitance for measurement purposes. With precision construction and use of suitable materials, they can have a permanence of value of 0.01% over a number of years for large capacitance values.

13.2.8.10 Vacuum and gas-filled capacitors

Vacuum capacitors are used mainly as high-voltage capacitors in airborne radio transmitting equipment and as blocking and decoupling capacitors in large industrial and transmitter equipments. They are made in values up to 500 pF for voltages up to 12 000 V peak. Gas-filled types are used for very high voltages—of the order of 250 000 V. Clean dry nitrogen may be used at pressures up to 10^5 kg/m^2. They are specially designed for each requirement.

13.3 Variable capacitors

Variable capacitors may be grouped into five general classes: precision types, general-purpose types, transmitter types, trimmers and special types such as phase shifters.